

Final Report

NASA PG&G Grant NAG5-10470 "Temporal Variability in the Accretion rate of Interplanetary Dust Using ^3He as a Tracer"

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1. Weekly Interplanetary Dust Sampling via ^3He

The first part of the research supported by this grant consists of weekly or semi-weekly sampling of interplanetary dust accumulations on several $\sim 1 \text{ m}^2$ surfaces distributed around the world, using ^3He as a tracer. The goal of the experiment is to better establish what sources of interplanetary dust carry ^3He to Earth. While it may be true that the IDPs accumulating to Earth represent the aggregation of particles from many different sources - comets, asteroids, Kuiper belt objects - it is also possible that strong biases exist in the collection efficiency of these particles by Earth. For example, Kortenkamp and Dermott (and Dermott's group in general [1,2]) have developed models of the orbital evolution of IDPs produced by the Themis, Eos, and Koronis asteroid families. These models suggest that much of the dust accreting to Earth is derived from these families. If so, then the long term record of IDP accumulation that we are obtaining from the seafloor sediment archive may be dominated by processes occurring within or the orbital characteristics of just these families. Alternatively, Messenger and coworkers [3, and personal communication] proposed that certain comets may dominate the IDP delivery at certain times as a consequence of their low geocentric encounter velocity. If this is true, then the long term record from the seafloor may indicate activity of just a few comets active at any one time. Both of these models make predictions for variations in the ^3He accretion rate over the Earth's annual cycle. Testing these predictions is the motivation for our ongoing experiment to collect IDP ^3He at weekly intervals, and the results are critical for the interpretation of the long-term record we are obtaining from the seafloor.

We monitored the IDP flux at Caltech and at the summit of Mauna Loa from 1997 to 2002, and a manuscript reporting these data is in preparation. As shown in Figures 1 and 2, the extraterrestrial ^3He accumulation is time varying, and there is a strong suggestion of an annual pattern, with high ^3He accretion in May-June and in December-March. This pattern is equally well-developed at Mauna Loa and Caltech, arguing against local meteorological effects. For example, a cross-correlation analysis suggests that the probability that the relationship between the two sites is random is $<1\%$. The pattern is apparent in 1999 and 2000, but is not well-developed in 2001. These data demonstrate high amplitude variability in ^3He accumulation from week to week and month to month, but remarkably, the average extraterrestrial ^3He flux implied by the data is in excellent agreement with the geologic average obtained from seafloor sediments (Figure 1).

The null hypothesis is that this variability represents some purely terrestrial process, such as settling of particles through the atmosphere or heating of entering IDPs. However it is difficult to reconcile the pattern observed at *both* sites with any known terrestrial process. This difficulty arises because the timing, absolute ^3He flux, and magnitude of variability observed in Southern California and Mauna Loa, separated by $\sim 3000 \text{ km}$ and located in fundamentally different climatic/meteorological regimes, are very similar. We tentatively reject a purely terrestrial process in controlling the ^3He flux to our collectors, and suggest that this variability has something to do with the orbital characteristics of the IDP sources accreting to Earth. The observed variability is not consistent with predictions by Dermott's group [1,2] in terms of timing

or magnitude, but may support the idea [3] that annual encounters with the dusty trails of certain comets may be important.

2. Extraterrestrial ^3He at Major Impact Boundaries

A second goal of this grant was to assess whether any of the major extinction boundaries in the geologic record are associated with elevated ^3He flux, for example, suggestive of a comet shower as we proposed for the late Eocene [5]. Interest in this topic has been renewed by recent reports of extraterrestrial noble gases in fullerenes at the Permian-Triassic boundary [6], and anomalously high Ir at the Triassic-Jurassic boundary [7], both of which have been attributed to major extraterrestrial impact events.

1. Permian-Triassic Boundary

As we reported in 2001, we were unable to reproduce the results of Becker et al. suggesting extraterrestrial ^3He in fullerenes at the P-Tr boundary in Meishan China [8]. Although these authors have responded to our work by claiming that the Meishan samples are heterogeneous, we analyzed a large suite of samples and found no ^3He at all; we are presently participating in the blind analysis of the alleged fullerene-bearing layer to sort out this controversy.

We also analyzed a large number of carbonate sediments around the Permian-Triassic boundary from the Gartnerkofel core from the Alps, at several sites in China, and at Tesoro, Italy. The results reveal no extraterrestrial ^3He . In all cases the measured ^3He is even lower than expected from normal nuclear processes in limestones (Figure 3). The absence of extraterrestrial ^3He is puzzling because we would expect some IDP-hosted ^3He regardless of whether there was an impact at this boundary. One possibility we have been investigating [9] is that these sediments have been sufficiently heated by metamorphism that the ^3He has been lost. As a result of this concern we are now more cautious to analyze only samples from rocks that have not been buried to great depths. This work was published in *Geology* last year [12].

Additional related work on this topic supported by a different grant was recently submitted for publication [13].

2. Jurassic-Cretaceous Boundary

We have largely completed analyses of a well-known Jurassic-Cretaceous section in the Italian Apennines ("Bosso"). As shown in Figure 4, there is clear evidence of extraterrestrial ^3He , but no strong case can be made for elevated ^3He flux at the boundary itself.

3. Completing a Moderately-High Resolution Record of Extraterrestrial ^3He Flux: a major asteroidal break up event at 8.2 Ma

A long-term goal of our work is to map out the ^3He flux throughout as much of geologic time as possible at a resolution sufficient to identify major solar system events such as comet showers and large collisions in the asteroid belt. Previously we had data from 72 to 32 Ma and from 2-0 Ma [10,11]. For this proposal, we analyzed the remainder of the Cenozoic.

In the new record by far the most surprising result is a substantial and long-lived (2 Myr) peak in extraterrestrial ^3He flux recorded at two deep sea sites at 8.2 Ma (Figure 5). This event is remarkably similar in magnitude and temporal progression to the Late Eocene event [5], but is not associated with any known impact craters. The absence of craters makes it more difficult to claim that the 8.2 Ma event is associated with a shower of long-period comets.

At the same time this work was in progress, Nesvorný et al. [14] were independently studying the orbital characteristics of asteroid families to establish when the families were produced by collision. Their most important conclusion was that the Veritas asteroid family was produced at 8.3 ± 0.5 Ma. This is a very large family, requiring collisional disruption of a body with a diameter of ~ 140 km. Indeed these authors predicted the occurrence of a ^3He spike in marine sediments of this age from the release of dust particles by the collision! Their data suggests that this was the largest event in the last ~ 40 Myr, at least for the families for which they could make reasonably accurate predictions.

Thus we conclude that the ~ 8.2 Ma event reflects the creation of the Veritas family. This is the first known evidence for such an event in the geologic record. At present I am collaborating with Nesvorný and Bottke to understand how the collision event produced the record we see. We believe our combined observations will provide better insight to dust production and orbital evolution of asteroid families following collision. We expect to submit a paper on this topic in Spring 2005.

4. Inventions

Nothing was invented in association with this grant.

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FIGURES

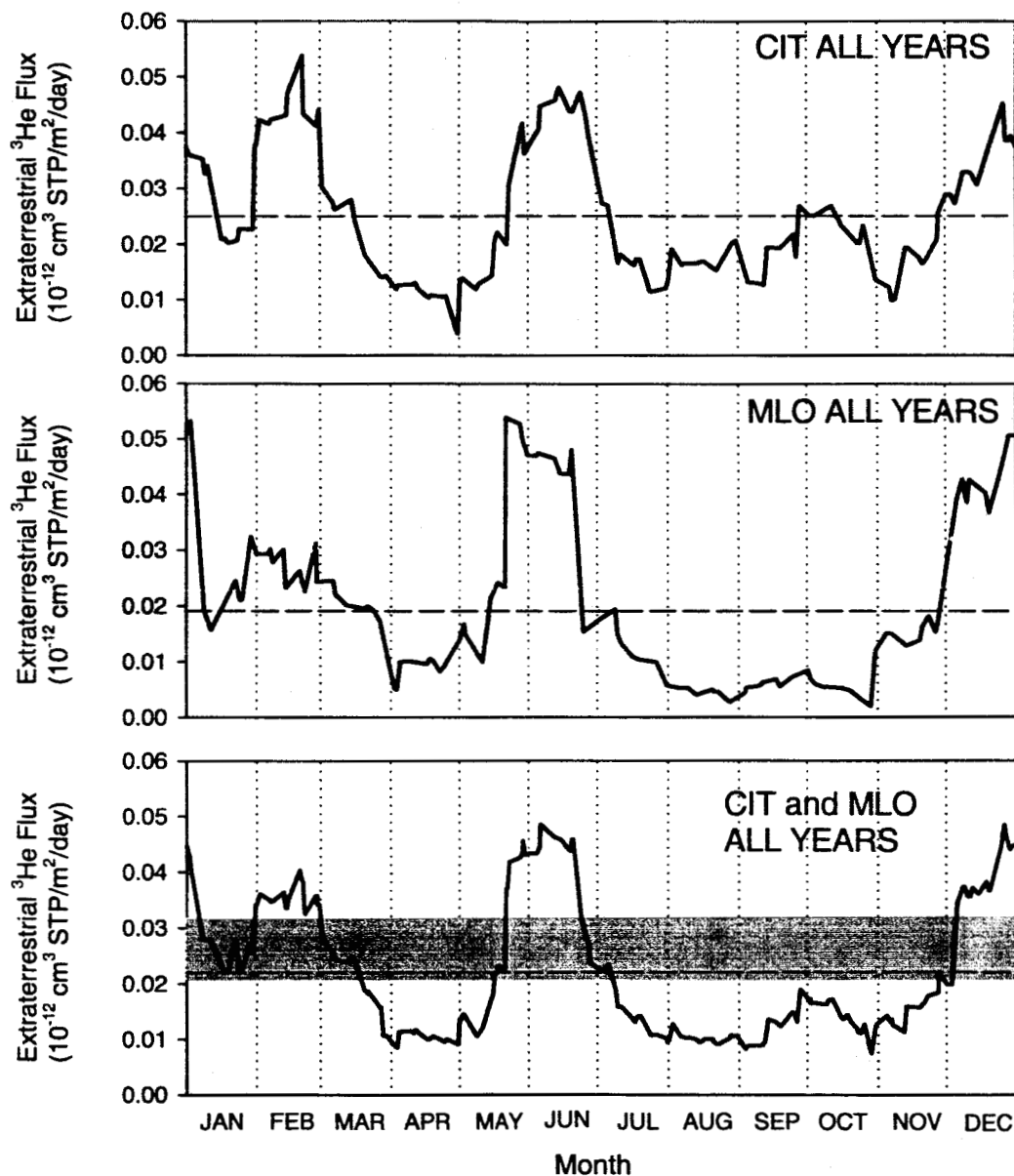


Figure 1. 30 Day running mean of the extraterrestrial ^3He flux obtained from collectors at Caltech (CIT) and Mauna Loa (MLO) and both sites combined for the years 1999, 2000, and 2001. The gray band in the lower panel is the average ^3He flux over the last ~ hundred kyrs inferred from seafloor sediments [4]. Note the similarity of the patterns at the two collection sites, arguing against strong local meteorological control on extraterrestrial ^3He flux.

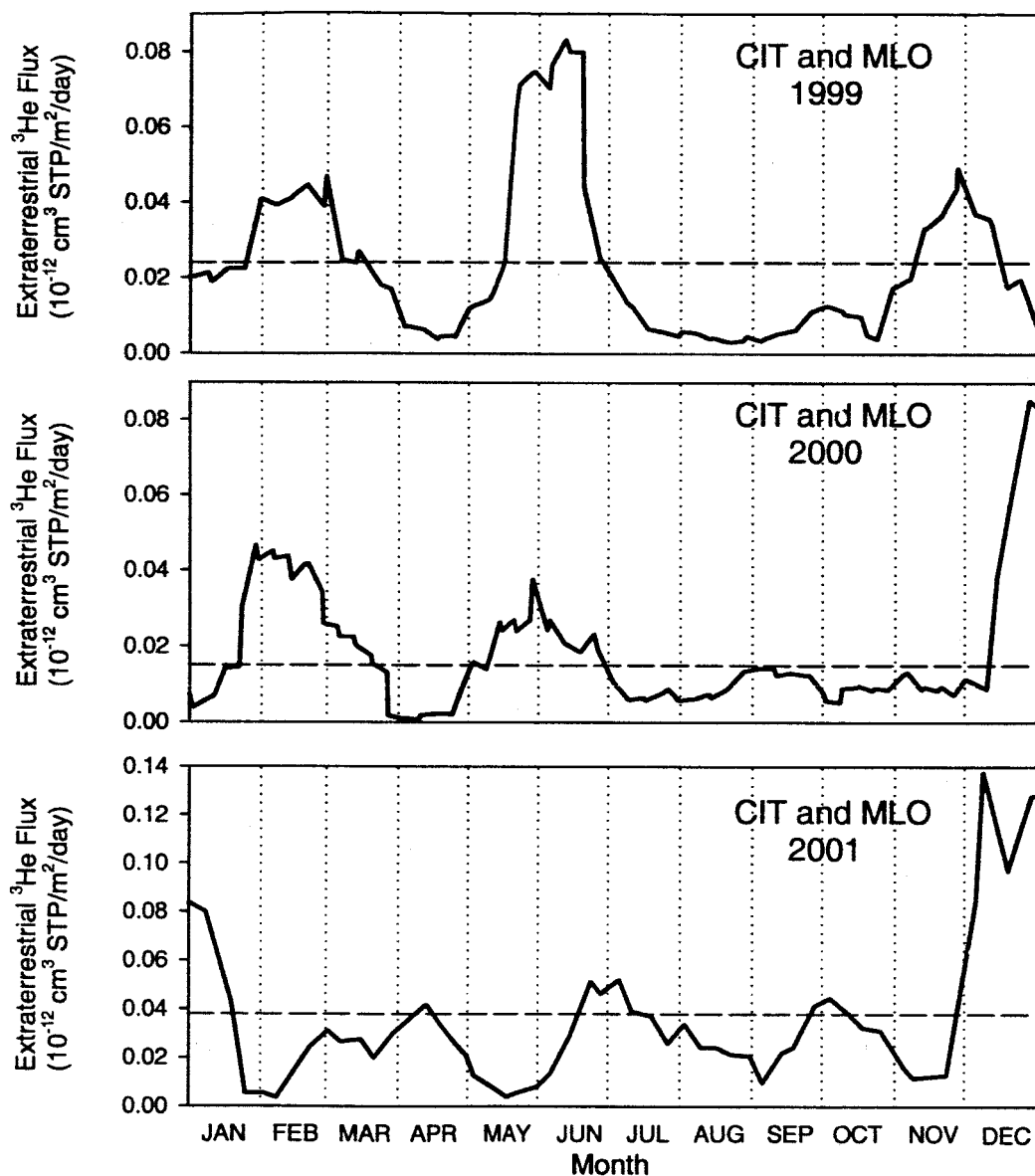


Figure 2. 30 Day running means of the flux of extraterrestrial ^3He to both the CIT and MLO collectors in each of the years 1999, 2000, and 2001. While 1999 and 2000 yielded rather similar patterns, the pattern in 2001 was distinctly different.

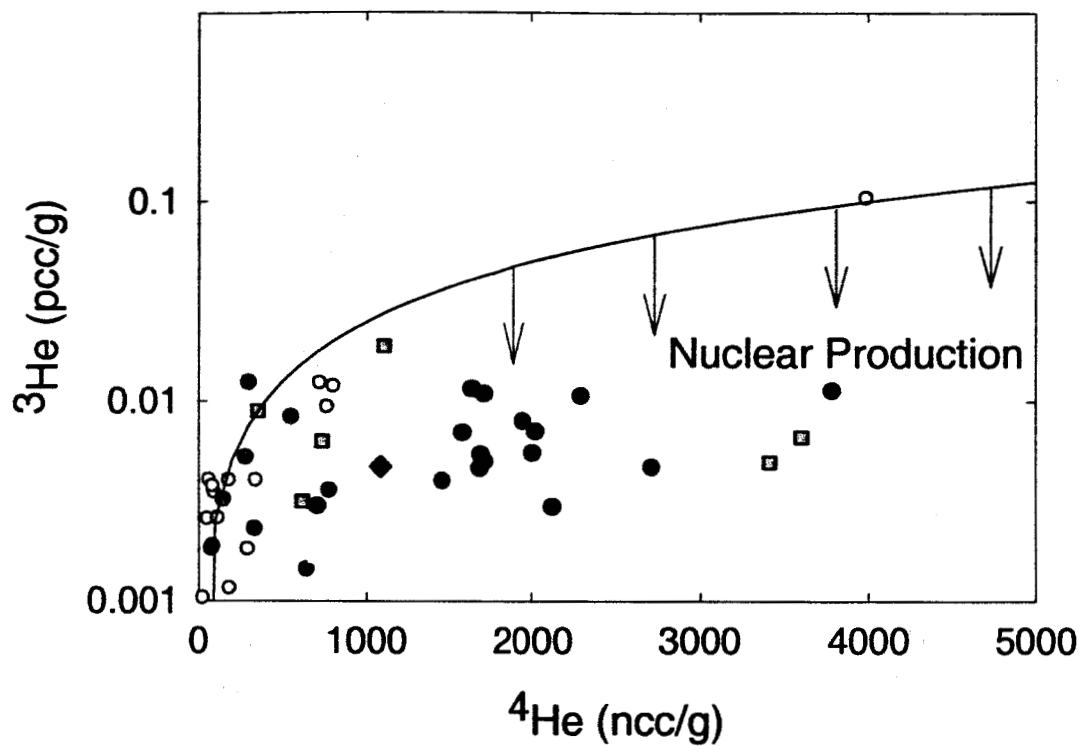


Figure 3. Helium isotopes measured at several P-Tr sections including Gartnerkofel (Alps), Meishan, Shangsì and a third Chinese section, and Tesoro (Italy). At none of these sites do we find ^3He above that expected for nuclear production in carbonate rocks. Thus there is no evidence for extraterrestrial ^3He at or near the Permian-Triassic boundary.

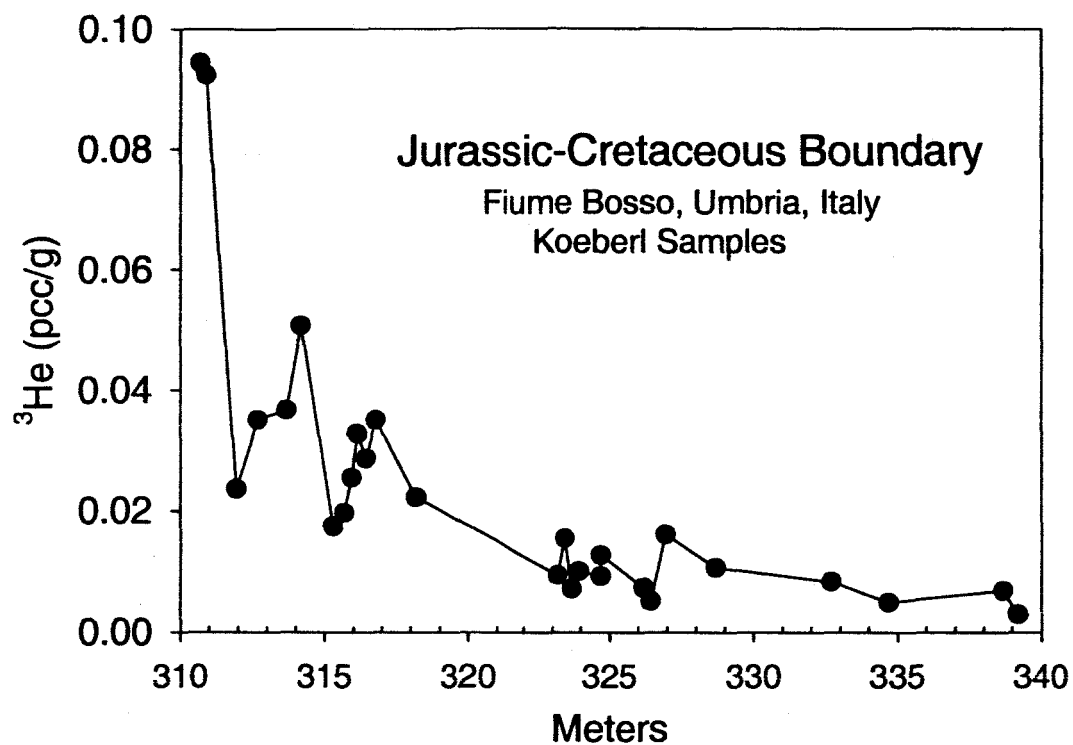


Figure 4. Extraterrestrial ^3He concentration across the Jurassic-Cretaceous boundary at the Bosso section. The extinction boundary is thought to be at ~ 320 meters. There is a substantially higher ^3He concentration in the late Jurassic than in the Cretaceous, but the high ^3He values are not concentrated at the boundary itself.

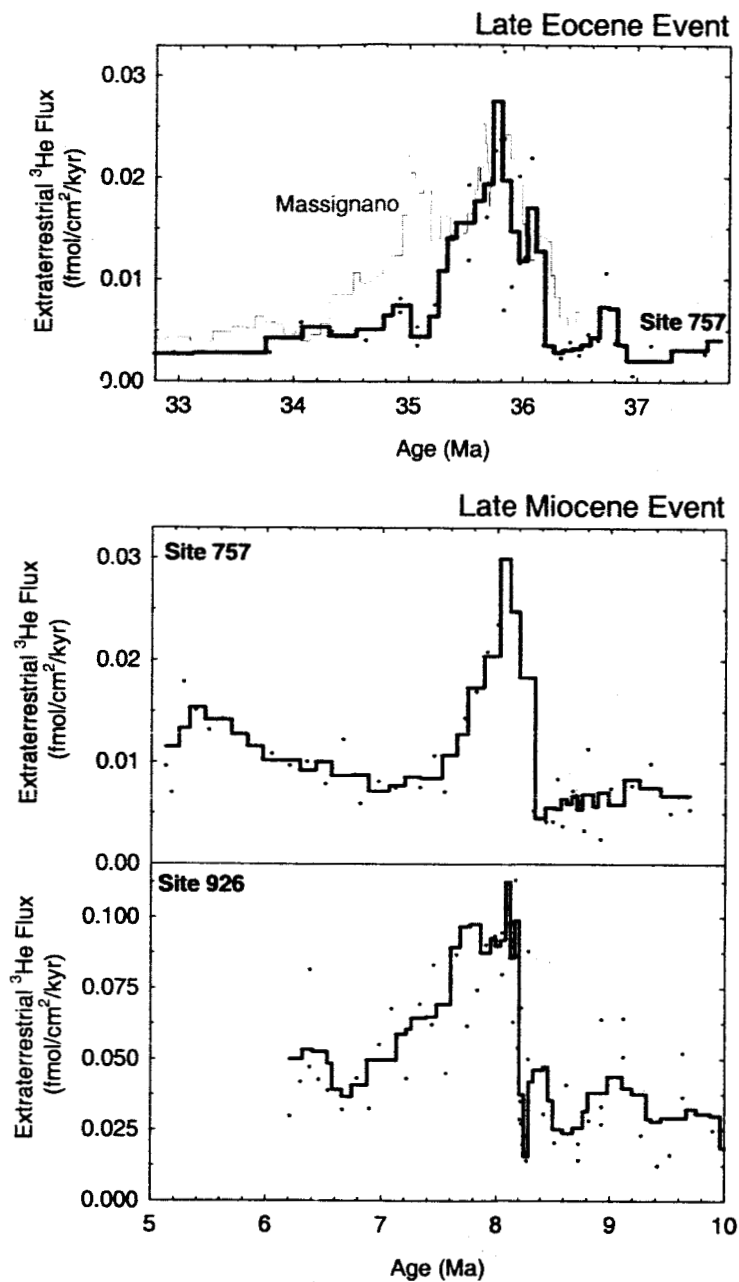


Figure 5. Extraterrestrial ^3He flux in the Late Eocene proposed comet shower [5] in the upper panel, and two crossings of the 8.2 Ma event shown at the same temporal scale. Note the similarity among the crossings and between the Late Eocene and 8.2 Ma events.